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# Rare Hadronic B Decays at BaBar

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On behalf of the BaBar Collaboration

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# Overview

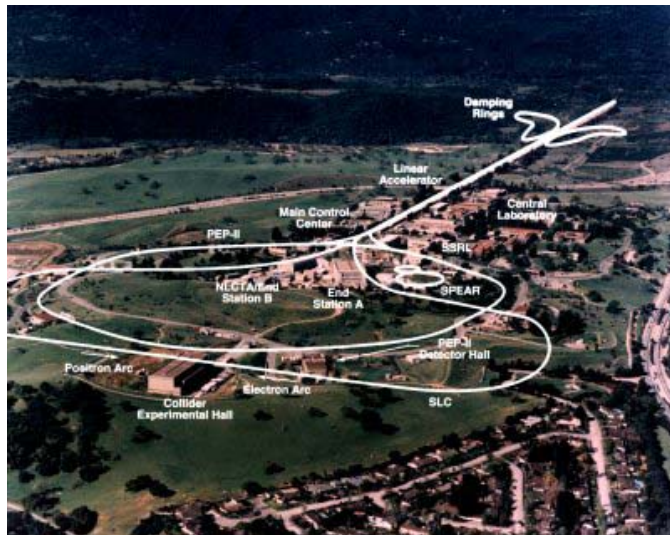
- Introduction to BaBar and PEP II
- Outline of analysis strategy
- Predominant sources of background
- BF and Charge Asymmetries for  $B^+ \rightarrow \eta\pi^+, \eta K^+, \eta'\pi^+$  and  $B^0 \rightarrow \eta K_s^0, \eta\omega$
- Search for  $B^0 \rightarrow D_s a_0$  and  $B^0 \rightarrow D_s a_2$
- $B^+ \rightarrow D^{(*)+}K_s$
- The use of c.c. states is implied throughout, unless otherwise stated

# Introduction to BaBar

BaBar collaboration:

- 600 physicists and engineers
- 80 institutions from 11 countries

Located at SLAC at the PEP II asymmetric energy collider



PEP II collides 9 GeV electrons and 3.1 GeV positrons at a center of mass energy of 10.58 GeV  $\rightarrow$   $Y(4S)$  resonance

20 MeV above  $B\bar{B}$  pair production threshold

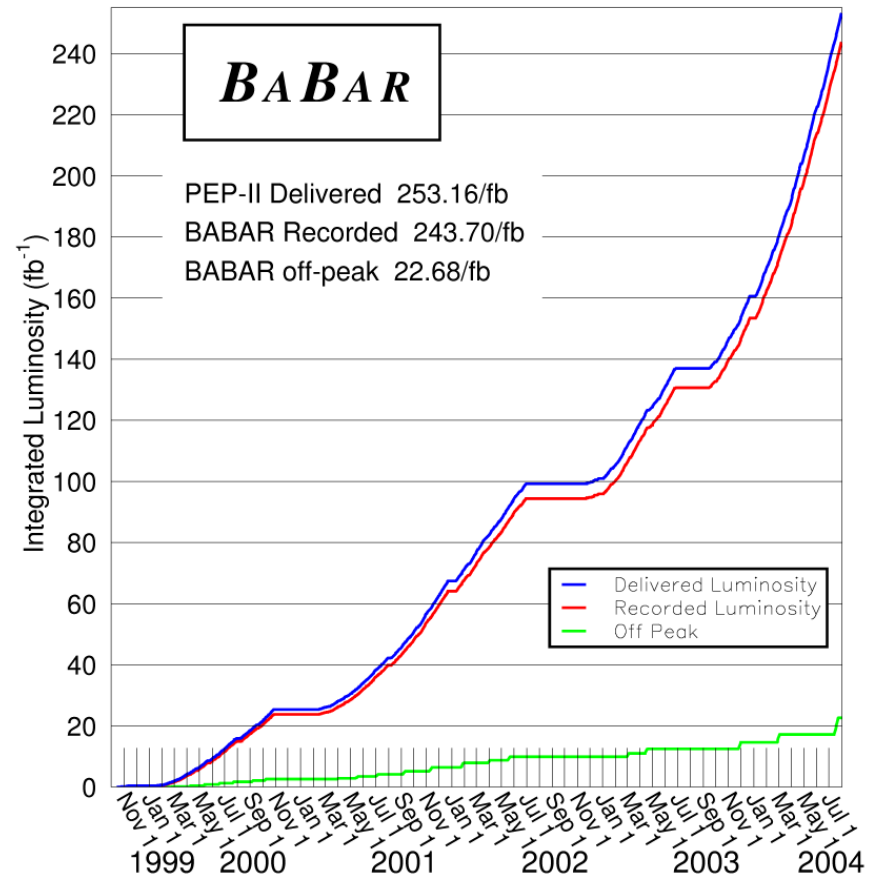
# Performance of PEP II and BaBar

2004/07/31 09:21

244 fb<sup>-1</sup> accumulated so far  
(9 March '05)

Now started running after a  
shutdown since September  
2004

Plan to accumulate double  
the current dataset by  
summer 2006



PEP II current luminosity above  $5 \times 10^{33} \text{cm}^{-2} \text{s}^{-1}$

# Common Analysis Strategy

All analyses presented use an unbinned maximum likelihood fit to the signal region

Discriminating variables:

$\Delta E$

$m_{ES}$

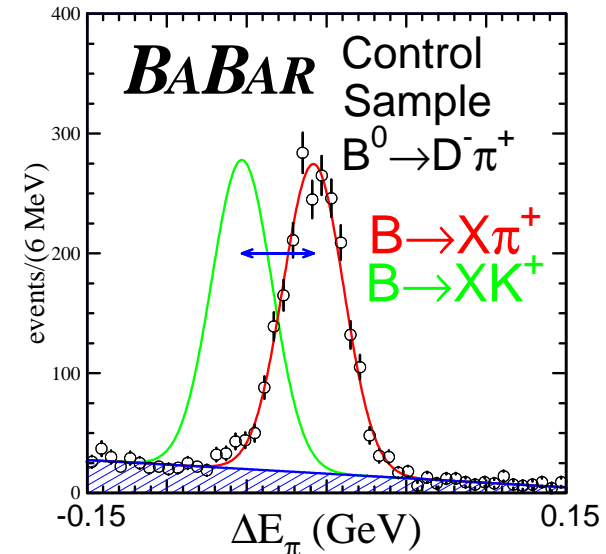
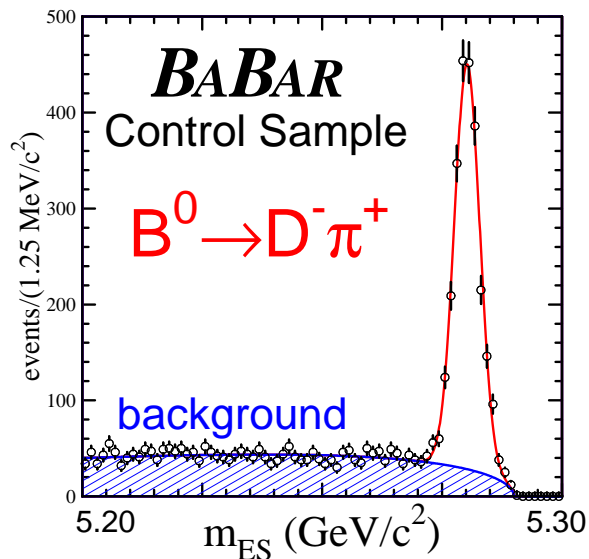
$$m_{ES} = \sqrt{E_{BEAM}^2 - p_B^{*2}}$$

$p_B^*$  is c. m. momentum of B

$$\Delta E^* = E_B^* - E_{BEAM}^*$$

Energy of the B Candidate in c. m. frame

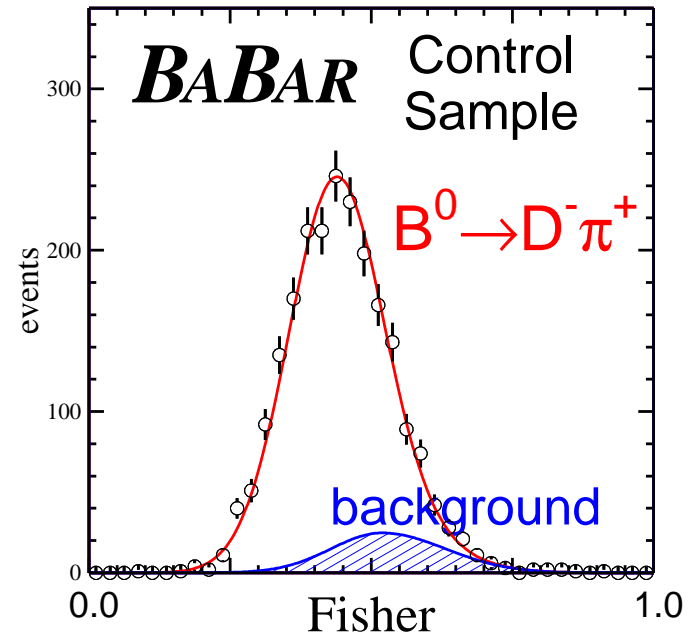
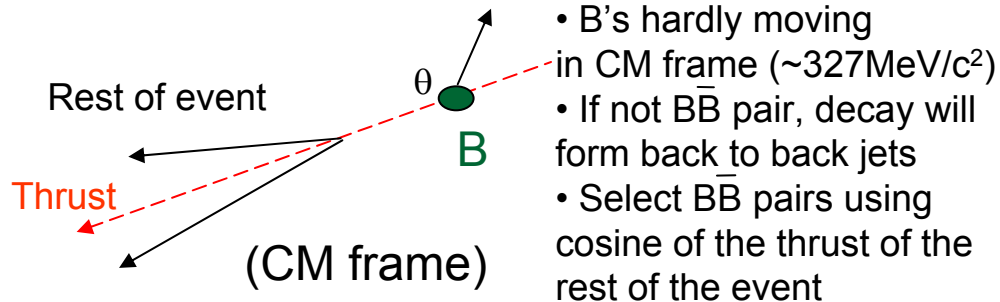
Energy of the beam in c.m. frame



# Continuum Background



## Thrust of the event



## Fisher discriminant

Combines the scalar sum of c. m. momentum of all tracks and photons (excluding those making up the B candidate)

# BF and Charge Asymmetries of

$B^+ \rightarrow \eta\pi^+, \eta K^+, \eta'\pi^+, \eta\rho^+$  and  $B^0 \rightarrow \eta K_s^0, \eta\omega$

**May proceed through CKM suppressed  $b \rightarrow u$  and loop  $b \rightarrow s$  transitions**  
**Amplitudes may be of similar size  $\rightarrow$  direct CP violation may be observable**  
**Branching fractions and charge asymmetries may also be sensitive to non - SM particle contributions via the loop diagram**

$B \rightarrow \eta K$  decays are interesting as they are suppressed by destructive interference between two loop amplitudes

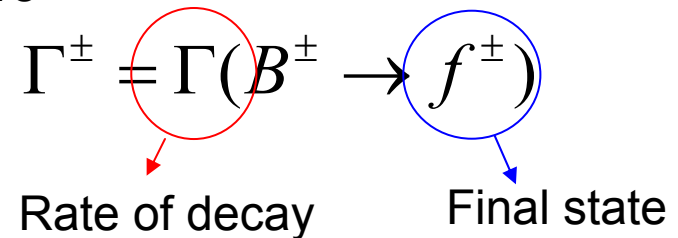
The  $b \rightarrow u$  tree amplitudes may interfere significantly with similar size  $b \rightarrow s$  loop amplitudes

 **DIRECT CP VIOLATION**

$$\text{Charge Asymmetry: } A_{ch} = \frac{\Gamma^- - \Gamma^+}{\Gamma^- + \Gamma^+}$$

where

$$\Gamma^\pm = \Gamma(B^\pm \rightarrow f^\pm)$$



# Selection and Fit

We select  $\eta$ ,  $\eta'$ ,  $\omega$ ,  $K_S^0$  and  $\pi^0$  using the following decays



$$\begin{aligned}\eta &\rightarrow \gamma\gamma (\eta_{\gamma\gamma}) \\ \eta &\rightarrow \pi^+ \pi^- \pi^0 \\ \eta' &\rightarrow \eta_{\gamma\gamma} \pi^+ \pi^- \\ \eta' &\rightarrow \rho^0 \gamma (\eta'_{\rho\gamma}) \\ \omega &\rightarrow \pi^+ \pi^- \pi^0 \\ K_S^0 &\rightarrow \pi^+ \pi^- \\ \pi^0 &\rightarrow \gamma\gamma\end{aligned}$$

## Continuum:

Again, large continuum background component  
→ suppressed by utilising difference in topology between signal and continuum (as before)

**B background is negligible for all modes except:**

$$\begin{aligned}B^+ &\rightarrow \eta_{\gamma\gamma} \pi^+ \\ B^+ &\rightarrow \eta_{\gamma\gamma} K^+ \\ B^+ &\rightarrow \eta \rho^+ \\ B^+ &\rightarrow \eta'_{\rho\gamma} \pi^+\end{aligned}$$

Model B Background with MC and individually account for it as a component in the fit

**Signal extracted using a Maximum Likelihood fit**

**Discriminating variables:**

**$\Delta E$**

**$m_{ES}$**

**Fisher discriminant**

**$K/\pi$  Particle ID**

**Cosine of helicity angle**  
( $\rho^+$  and  $\omega$ )

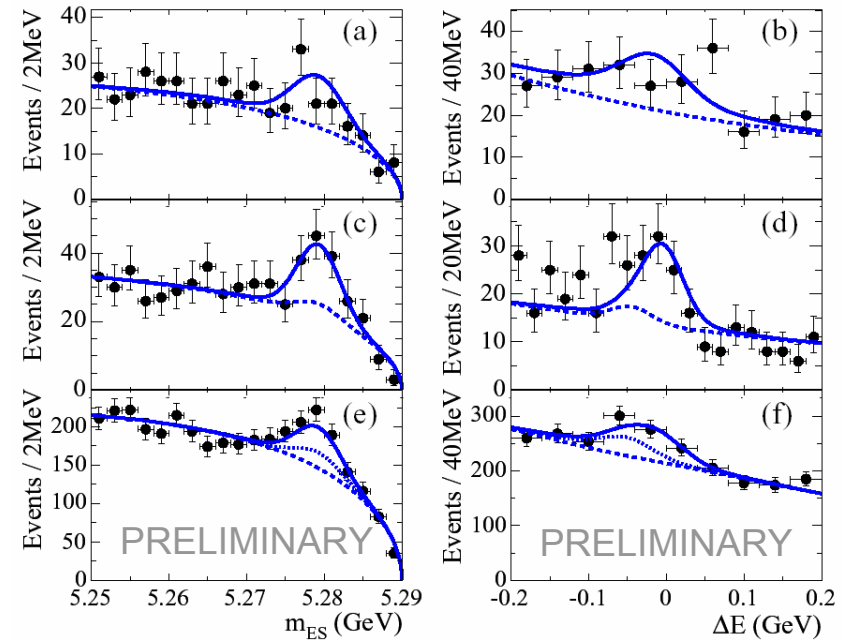
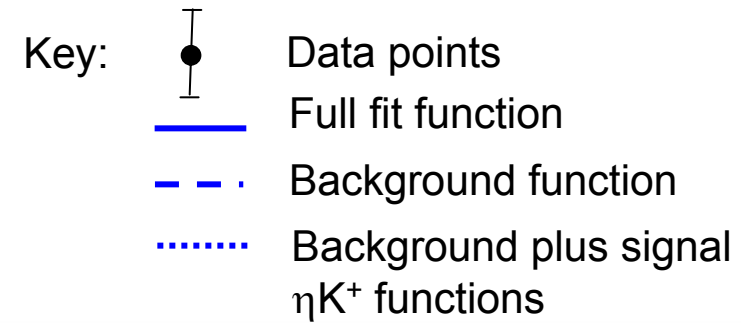
# Results (230 million $B\bar{B}$ pairs)

Mode	BF ( $10^{-6}$ )	$A_{ch}$
$\eta \pi^+$	$5.1 \pm 0.6 \pm 0.3$	$-0.13 \pm 0.12 \pm 0.01$
$\eta K^+$	$3.3 \pm 0.6 \pm 0.3$	$-0.20 \pm 0.15 \pm 0.01$
$\eta K^0$	$1.5 \pm 0.7 \pm 0.1 (< 2.5)$	
$\eta \omega$	$1.0 \pm 0.5 \pm 0.2 (< 1.9)$	
$\eta \rho^+$	$8.4 \pm 1.9 \pm 1.1$	$0.02 \pm 0.18 \pm 0.02$
$\eta' \pi^+$	$4.0 \pm 0.8 \pm 0.4$	$0.14 \pm 0.16 \pm 0.01$

Charge asymmetries all consistent with zero

All branching fractions consistent with previous theoretical predictions

$B^+ \rightarrow \eta \rho^+$  observed at  $4.7\sigma$   
 $B^+ \rightarrow \eta' \pi^+$  observed at  $5.4\sigma$



**Plots:** (a), (b):  $B^+ \rightarrow \eta \rho^+$   
(c), (d):  $B^+ \rightarrow \eta' \pi^+$   
(e), (f): combined  $B^+ \rightarrow \eta \pi^+$   
and  $B^+ \rightarrow \eta K^+$

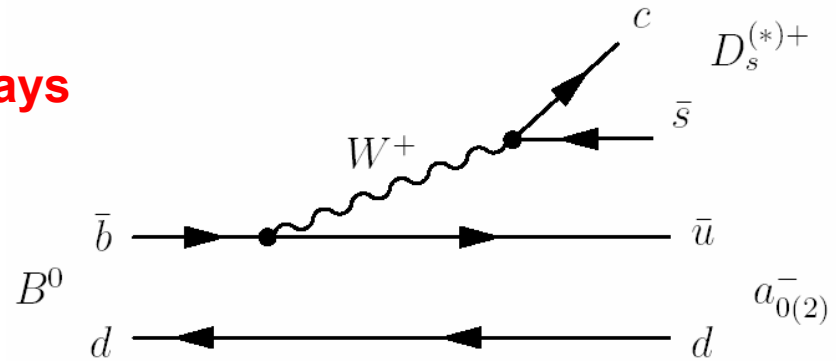
# Search for $B^0 \rightarrow D_s^+ a_0^-$ and $B^0 \rightarrow D_s^+ a_2^-$

→ A test of factorisation in B decays

## Recent results:

Decay mode	$\mathcal{B} (\times 10^{-5})$
$B^0 \rightarrow D_s^+ \pi^-$	$3.2 \pm 0.9 \pm 1.0$
$B^0 \rightarrow D_s^+ \rho^-$	$< 1.9$
$B^0 \rightarrow a_0^- \pi^+$	$< 0.51$

Phys. Rev. Lett. **90**, 191803 (2003)  
 hep-ex/0408029  
 Phys. Rev. D **70**, 111102 (2004)



- Predict  $\text{BF}(B^0 \rightarrow D_s^+ a_0^-)$  from  $\text{BF}(B^0 \rightarrow D_s^+ \pi^+)$  and ratio of  $a_0^-$  to  $\pi$  form factors ( $>1$ ) → no theoretical prediction
- Factorisation suggests  $\text{BF}(B^0 \rightarrow a_0^- \pi^+)$  should be suppressed by a factor ( $f_\pi/f_{D_s}$ )  $\sim 4-5$  to  $\text{BF}(B^0 \rightarrow D_s^+ a_0^-)$  unless there is destructive interference from penguin contributions
- $\text{BF}(B^0 \rightarrow D_s^+ \rho^+)$  has a low limit → could indicate form factor for  $\rho$  is lower than for  $\pi$  or that factorisation fails to work in this case

## BF PREDICTIONS

Decay mode	$V_{cb} (V_{ub})$ mediated $\mathcal{B} (\times 10^{-6})$
$B^0 \rightarrow D^- a_0^+$	$1.1 - 4.0 / (2.1)$
$B^0 \rightarrow D^{*-} a_0^+$	$1.0 - 3.7 / (1.9)$
$B^0 \rightarrow D^- a_2^+$	$0.4 - 1.7 / (-)$
$B^0 \rightarrow D^{*-} a_2^+$	$0.3 - 1.5 / (-)$

hep-ph/0105194

# Event Selection and ML Fit

$$D_s^+ \rightarrow \pi^+ \phi, (\phi \rightarrow K^+ K^-)$$


$$D_s^+ \rightarrow K^+ K_S^0, (K_S^0 \rightarrow \pi^+ \pi^-)$$

$$D_s^+ \rightarrow K^+ \bar{K}^{*0}, (\bar{K}^{*0} \rightarrow \pi^+ K^-)$$

Charged Kaon selection efficiency > 90%

Use polarisation of  $K^{*0}$  and  $\phi$  to discriminate against background

BF assumed to be 100% for  $a_0^+$  (980)  
and PDG2004 value for  $a_2^+$  (1320)



$$a_0^+, a_2^+ \rightarrow \eta \pi^+ (\eta \rightarrow \gamma \gamma)$$

Remaining background from continuum  
Use the thrust of the event and a  
**Fischer discriminant** to suppress  
background

The more isotropic the event,  
the larger the Fisher value

**Signal extracted using a Maximum Likelihood fit**

Discriminating variables:  $\Delta E$   
 $m_{ES}$



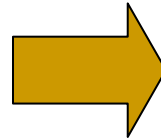
Continuum background modelled using  
simulated background events

# Results (230 million $B\bar{B}$ pairs)

Upper limits on branching ratios (at 90% CL)

$$B(B^0 \rightarrow D_s^+ a_0^-) = (1.9_{-1.4}^{+1.8}) \times 10^{-5}$$

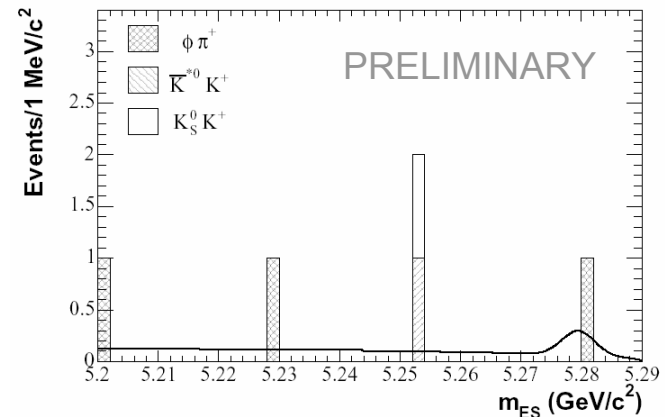
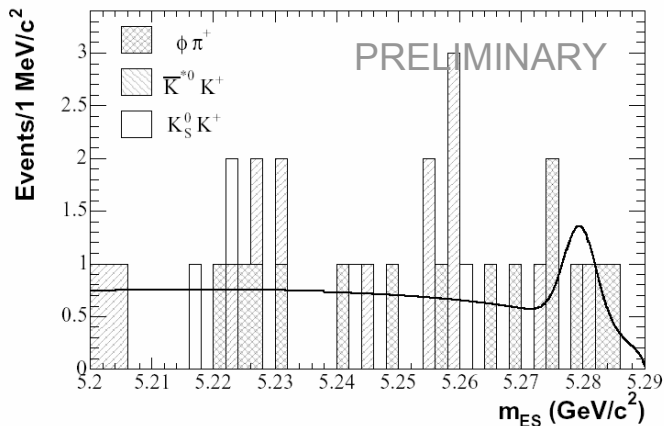
$$B(B^0 \rightarrow D_s^+ a_2^-) = (8_{-8}^{+14}) \times 10^{-5}$$

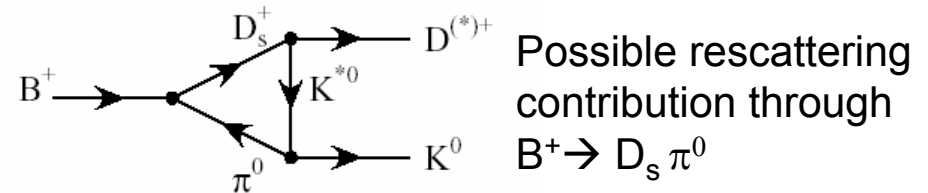
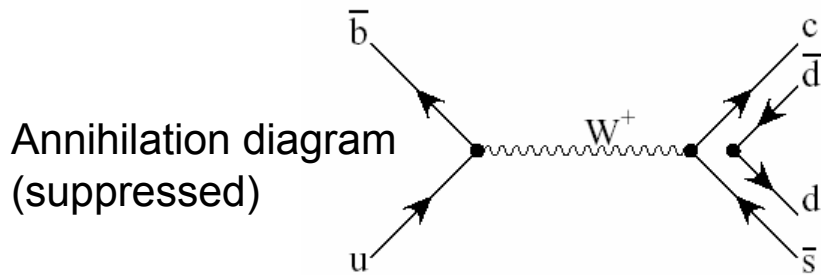


$$B(B^0 \rightarrow D_s^+ a_0^-) < 4.0 \times 10^{-5}$$

$$B(B^0 \rightarrow D_s^+ a_2^-) < 2.5 \times 10^{-4}$$

Systematic errors dominated by 25% uncertainty in BF ( $D_s \rightarrow \phi\pi^+$ ); also systematic Errors from  $m_{ES}$  shape (21%) and reconstruction efficiencies





Annihilation diagrams can't be calculated through factorisation  
**→ No reliable theoretical prediction**

Strong rescattering could enhance rate to level of tree-mediated processes  
 →  $10^{-5}$   
 →  $10^{-8}$  if no rescattering

Only one W exchange decay has been observed in B mesons:

$B^0 \rightarrow D_s^- K^+$  BF =  $(3.2 \pm 1.0 \pm 1.0) \times 10^{-5}$   
 Phys. Rev. Lett. **90**, 181803 (2003)

No annihilations have been observed in B decays

$B^+ \rightarrow D^{(*)+} K_s$  has a clean experimental signature → good place to look

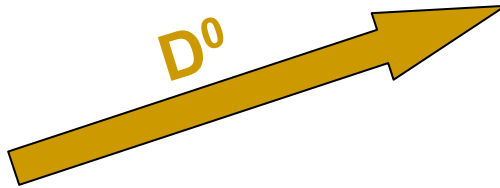
**Understanding annihilations is important to infer amplitudes that can't be measured directly**

# Selection and Fit

$$D^+ \rightarrow K^- \pi^+ \pi^-$$

$$D^+ \rightarrow K_S^0 \pi^+$$

$$D^{*+} \rightarrow D^0 \pi^+$$



$$D^0 \rightarrow K^- \pi^+$$

$$D^0 \rightarrow K^- \pi^+ \pi^0$$

$$D^0 \rightarrow K^- \pi^+ \pi^- \pi^0$$

$$D^0 \rightarrow K_S^0 \pi^+ \pi^-$$

**Continuum background rejected using topological variables (as in previous decay modes)**

## Background from mis-reconstructed B decays

- Study using MC simulation
- Model background in the fit

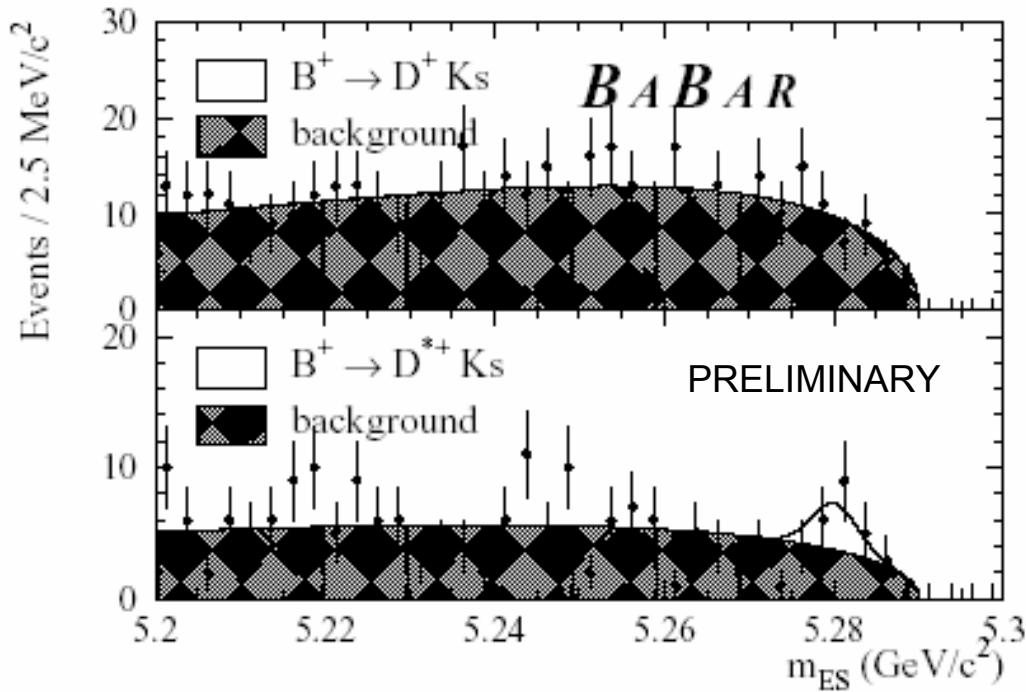
Extract signal using Maximum Likelihood fit on variables:

$\Delta E$

$m_{ES}$

The main B background comes from well known  $B^0 \rightarrow D^{(*)-} X^+$  decays ( $X^+ = \pi^+, \rho^+, a_1^+$ )

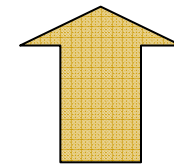
# Results (226 million BB pairs)



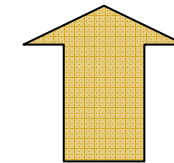
Upper Limits at 90% CL:

$$B(B^+ \rightarrow D^+ K^0) < 0.5 \times 10^{-5}$$

$$B(B^+ \rightarrow D^{*+} K^0) < 0.9 \times 10^{-5}$$



**NO EVIDENCE OF SIGNAL**



Both statistical and systematic errors included in quoted error

$$B(B^+ \rightarrow D^+ K^0) = (-0.28^{+0.61}_{-0.56}) \times 10^{-5}$$

$$B(B^+ \rightarrow D^{*+} K^0) = (0.28^{+0.44}_{-0.41}) \times 10^{-5}$$

# Summary

- $B^+ \rightarrow \eta \rho^+$  observed at  $4.7\sigma$
- $B^+ \rightarrow \eta' \pi^+$  observed at  $5.4\sigma$
- Charge asymmetries for  $B^+ \rightarrow \eta\pi^+$ ,  $\eta K^+$ ,  $\eta'\pi^+$  and  $B^0 \rightarrow \eta K^0$ ,  $\eta\omega$  all consistent with zero
- New upper limits on  $B^0 \rightarrow D_S a_0$  and  $B^0 \rightarrow D_S a_2$
- New upper limits on  $B^+ \rightarrow D^+ K_S$  and  $B^+ \rightarrow D^{(*)+} K_S^0$